

**SIZE DISTRIBUTION OF MAGNETITE IN CARBONATE GLOBULES OF ALH84001 MARTIAN METEORITE.** D. C. Golden<sup>1</sup>, K. L. Thomas-Keprta<sup>2</sup>, D. S. McKay<sup>3</sup>, S. J. Wentworth<sup>2</sup>, H. Vali<sup>4</sup> and D. W. Ming<sup>3</sup>

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**Introduction** Magnetite is an ubiquitous mineral in meteorites and the particle size of these grains typically range from a few nanometers to several micrometers [1]. Occurrence of magnetite and sulfides in martian meteorite ALH84001 has been suggested as possible evidence for biogenic activity [2]. Known biogenic magnetites on Earth occupy a narrow range of sizes and are usually single-domain, often occur in chains of similar-sized particles and exhibit several morphologies: cubic, prismatic and bullet or tear-drop shaped [3]. Magnetite produced by magnetotactic bacteria is a carrier of natural remnance magnetism (NRM) in terrestrial sedimentary environments. In addition to magnetotactic bacteria which produce magnetite intracellularly, there are many types of bacteria which produce magnetite extracellularly; e.g., thermophilic [4] and sulphate reducing [5] bacteria. If the magnetite in the carbonate globules of ALH84001 meteorite is of biogenic origin we do not know the nature of the organism which produced them. The shape and size analysis data of the magnetite in the carbonate globules of ALH84001 will provide an important basis for comparison with terrestrial biogenic magnetite. Therefore, the objective of this study was to study the size and shape of magnetite in the carbonate globules of ALH84001 in comparison to terrestrial biogenic magnetite.

**Samples and Methods** Carbonate globules from the ALH84001 meteorite were removed from fractured surfaces using a sticky tape and transferred onto a pre-cast epoxy block and embedded in a drop of Embed812 epoxy. The block was trimmed and ultramicrotomed using a Porter Blum MT-2 ultramicrotome equipped with a diamond knife. Sections included portions of globule interiors and also the iron- and sulfur-rich rims. The approximately 70-nm thin sections were mounted on a holey-C substrate on a Cu-grid and analyzed using a JEOL 2000FX TEM. The magnetite grains were identified by a combination of analytical techniques including EDS analysis, electron diffraction, and lattice fringe imaging. Particle measurements were done using negative images and a 10x loupe. A sample of magnetite from magnetotactic bacteria strain MS-1 was used for comparison. The population means were compared by a single factor ANOVA.

**Results and Discussion** Mean particle diameter for the magnetite in the carbonate globule (42.9 nm) interior was not significantly different from that of the rim magnetite (38.5 nm) [Figs. 1a, b]. However, the magnetite distribution within the carbonate was much more sparse and the total number available for measurements was less. Therefore, the contribution of the carbonate magnetite to the total magnetite was not significant. This can be seen from the similarity of the two histograms for the magnetite in the rim versus that of the whole carbonate globule (Figs. 1b, c). The distribution of particle diameters of magnetite from bacterial strain MS-1 is narrower (variance = 69, df = 88) than that of the magnetite from the carbonate globules in ALH84001 (variance=281, df =141; Fig. 1c, d); however, the mean value (40.4 nm) is not significantly different from that of the magnetite population in the carbonate globule. Length to width axial ratio (aspect ratio) for the magnetite in the carbonate globule ranged from 1 to 2.3 and that for the rim from 1 to 3.8 and the average value was nearly 1.4 for both populations. Both these values along with that for MS-1 when plotted on the theoretically derived stability field diagram of Butler and Banerjee [6] falls in the single-domain region (Fig. 2). The magnetite in the carbonate globule has several morphologies (e.g.; cubo-octahedral, cubic, hexagonal prism, and elongated cubo-octahedral) but the outlines as seen in TEM can be hexagonal, square, rounded, or irregular (not shown). We did not observe any platy or needle shaped crystals in the samples we examined. The majority of the crystals observed in the carbonate interior were euhedral and those from the rim were, euhedral, rounded or irregular shaped. Magnetite crystals produced by bacterial strain MS-1 are predominantly cubo-octahedral and are relatively uniform, and the mean size of these magnetite crystals (40.4 nm) fell within the magnetite population for the carbonate globule. However, Vali and Kirschvink [3] reported magnetite from other bacteria strains with shapes ranging from cubo-octahedral, pseudohexagonal prisms, to tooth or bullet shaped with or without bends. Except for the cubo-octahedral form all the other morphologies exhibit a wide range of particle sizes. For example, these authors reported a needle shaped magnetite from a bacterium from Moorsee with a particle length of 300 nm [3] and an aspect

ratio of 10. This is the extreme that has been reported for biogenic magnetite. In contrast to the magnetite dimensions in the carbonates the particle diameters of magnetite from C1 carbonaceous chondrite Orgueil range from 0.1 to 1.2  $\mu\text{m}$  [1] and differs significantly from both the bacterial magnetite and those from ALH84001 carbonate globules.

**Conclusions** The mean particle size and the size distribution of the magnetite crystals in carbonate globules of ALH84001 meteorite are comparable with those of bacterial magnetite from MS-1. The aspect ratios were similar for the magnetite population in the carbonates and those from the bacterial strain MS-1 and fall within the single domain size range. Further work is needed to evaluate particle size properties of biogenic magnetite including those from bacteria (dissimilatory and assimilatory) that produce

magnetite of different morphologies. More carbonate globules in ALH84001 meteorite should also be studied to improve the statistical validity of the measurements.

**References:** [1]. Kerridge, J.F. (1970) EPSL 9:299. [2] McKay, D.S. et al. (1996) Science: 273:924 [3] Vali, H. and Kirschvink, J. (1990) Iron Biominerals (ed. R. B. Frankel and R. P. Blakemore) Plenum Press, N.Y., pp.97. [4] Zhang, C. et al. (1997) SPIE proceedings (submitted). [5] Sakaguchi, T. et al. (1993) Nature 365:47. [6] Butler, R.F. and Banerjee, S.K. (1975) J. Geophys. Res. 80:4049.

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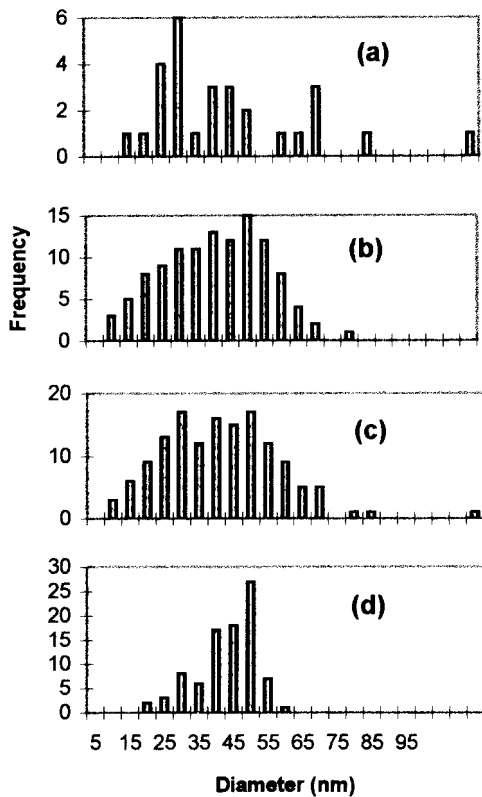


Figure 1. The distribution of particle diameters for magnetite crystals from: (a) the interior of the ALH84001 carbonate globule without the rim, (b) the rim region of the ALH84001 carbonate globule, (c) the whole carbonate globule in ALH84001, and (d) bacterial magnetite from strain MS-1.

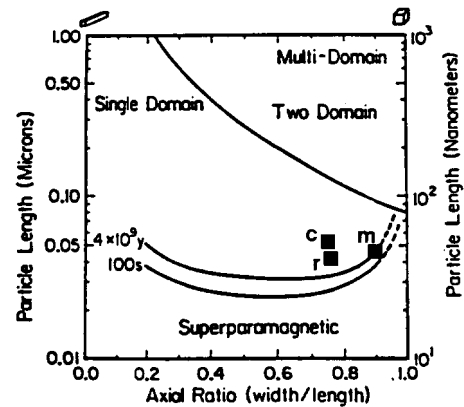


Figure 2. Average grain size values for magnetite in the interior of the carbonate globule (c), in the rim (r) and from the bacterial strain MS-1 (m) plotted on the theoretically derived stability field diagram of Butler and Banerjee [6]. All three values fall in the single-domain region. The superparamagnetic threshold is shown for critical relaxation times of 100 s and  $4 \times 10^9$  yr.